Sea Truth Validation of Bio-Optical Models for 'A' And 'Bb'; Application to Heat Budget Models and the Effects of Biology on Ocean Thermal Structure.

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LONG-TERM GOALS

The long-term goal is to obtain better measurements of the inherent optical properties of seawater (IOPs, absorption 'a' and back-scattering 'bb') to provide better parameterizations of the absorption of light by seawater, to improve heat budget models of surface ocean stratification. The proposed work will extend on-going research at PML on furthering the understanding, accurate interpretation and exploitation of remotely sensed data of ocean color, from sensors: SeaWiFS, MODIS (NASA), MERIS (ESA). Assimilation of data from these sensors into 1-D and 3-D ocean circulation models is a long-term goal.

OBJECTIVES

The primary objective is to develop bio-optical models, that will have the inherent optical properties (IOPs, absorption 'a' and back-scattering 'bb') as the main variables, so that remotely sensed data of ocean color can be interpreted and exploited by including the effects of absorption and scattering of solar radiation in heat-budget models of upper-ocean physical structure to improve accuracy. The work with ONR will focus on model validation, acquiring ground-truth data and in situ measurements of the IOPs and AOPs (inter-relationships). The effects of biology (phytoplankton) on vertical thermal structure will be studied.

The development of bio-optical models, with IOPs as the main variables, is on going and part of the core strategic projects of PML, part funded by NERC. The acquisition of ground truth data of IOPs is new, which ONR/NICOP provide part funding.

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14. ABSTRACT
The long-term goal is to obtain better measurements of the inherent optical properties of seawater (IOPs, absorption ?a? and back-scattering ?bb?) to provide better parameterizations of the absorption of light by seawater, to improve heat budget models of surface ocean stratification. The proposed work will extend on-going research at PML on furthering the understanding, accurate interpretation and exploitation of remotely sensed data of ocean color, from sensors: SeaWiFS, MODIS (NASA), MERIS (ESA). Assimilation of data from these sensors into 1-D and 3-D ocean circulation models is a long-term goal.

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APPROACH

The technical approach is to develop forward and inverse models that determine the relationship between IOPs and reflectance. IOP measurements are made from both cruises and time series sites to validate and test these models. The models are applied to remotely sensed and in-situ measures of reflectance, and the retrievals from these models are evaluated and quality assured. The intention is to use the quality assured satellite data to evaluate the effects of thermal structure by using these IOP to force simple 1D models.

Gerald Moore is primarily responsible for the modeling, and James Fishwick for maintaining the time series sites at Plymouth. Both have participated in the bio-optical cruises.

WORK COMPLETED

This final report (contract concluded 01/05) comes after the conclusion of the diverse field campaigns including the weekly time series measurements at stations L4 and E1 that have been undertaken in the previous years. The work at L4 and E1 has continued through 2004-05 and there have been further AMT cruises (AMT-14, -15, -16) in 2004 and the spring of 2005. None of these data have been added to the data base used to address the key long term goals: "The long-term goal is to obtain better measurements of the inherent optical properties of seawater (IOPs, absorption 'a' and back-scattering 'bb') to provide better parameterizations of the absorption of light by seawater, to improve heat budget models of surface ocean stratification."

These data are available to ONR personnel or their authorised funded researchers on request.

The application of using new data on a and bb to drive the General Ocean Turbulence Model (GOTM – http://www.gotm.net) has not progressed to completion but again we are pleased to communicate these data to ONR staff/ funded researchers as requested.

The significant accomplishments featured in the results sections below, have been to analyse and evaluate the data derived over the previous 4 years and earlier years and gain insight into fundamental functional relationships between photosynthesis, pigments, resultant optical properties and ocean colour as observed remotely from space.

RESULTS

The table below lists the validation data sets worked up this year and included in the analyses. Note some data have been acquired from collaborators outside the PML-based project (Baltic, N. Sea).

Table of Validation Datasets (Bold worked up this year; Surface database N ~800).

1) AMT 12 – **VSF, AC-9**, HPLC, **Optics**, PABS

2) AMT 13 – HPLC, **Optics**, **PABS**

3) AOPEX – **VSF, AC-9, b_b, Optics**

4) Baltic – Chl, **VSF, AC-9, PABS, Optics, aysbpa**, TSM, Phycobillin

5) Bencal – **b_b,** PABS, HPLC, **Optics**, TSM

6) AMT6 – HPLC, PABS, Optics, **[AC-9 – 490,555]**

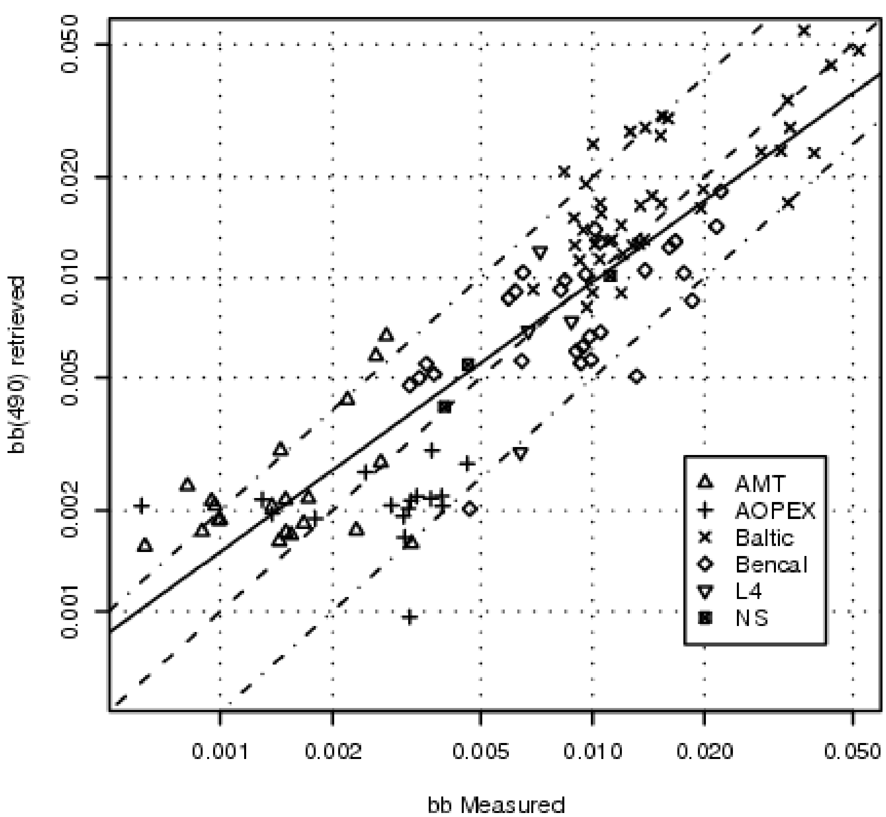
7) COLORS – HPLC, PABS, Optics, a_{ysbpa}, AC-9, TSM

8) L4 – HPLC, PABS, a_{ysbpa}, **b_b**, Optics,TSM

9) NS – HPLC(?), PABS, Optics, **b_b**, TSM

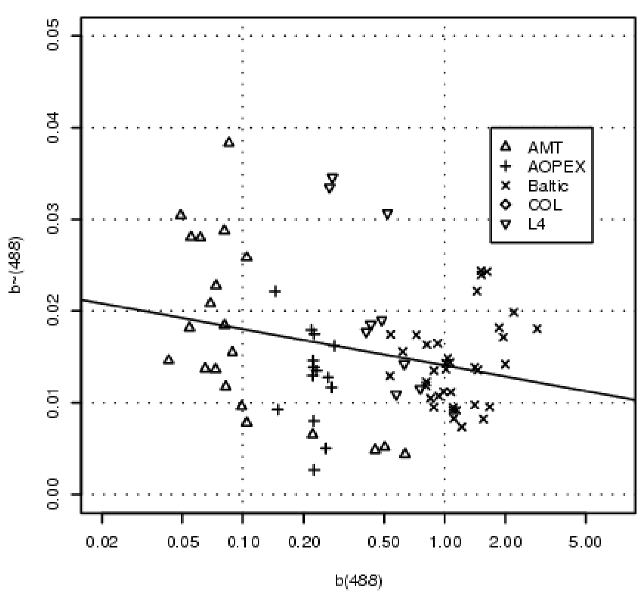
10) Coastlooc HPLC, PABS, TSM, a_{ysbpa}, AC-9

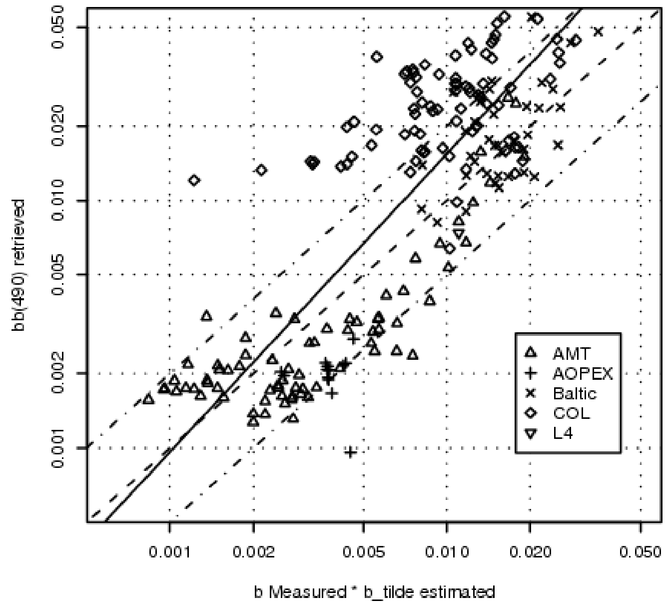
These data have been used to validate the IOP model (previously Moore & Aiken, now revised as Moore, Aiken et al and re-submitted to Applied Optics); a copy of this paper is available on request. The model is distinctive in that none of the key parameterisations use relationships between the IOPs and geophysical optically active water constutients such as Chlorophyll-a.



R Squared 0.7692536
RMS 0.01342134
BIAS 0.1925752
a = 0.4019612
n = 0.8083838
N - 113

Figure 1 below shows the combined data set of measured $b_b(490)$ data compared to the output of the IOP model $b_b(490)$ retrieved.



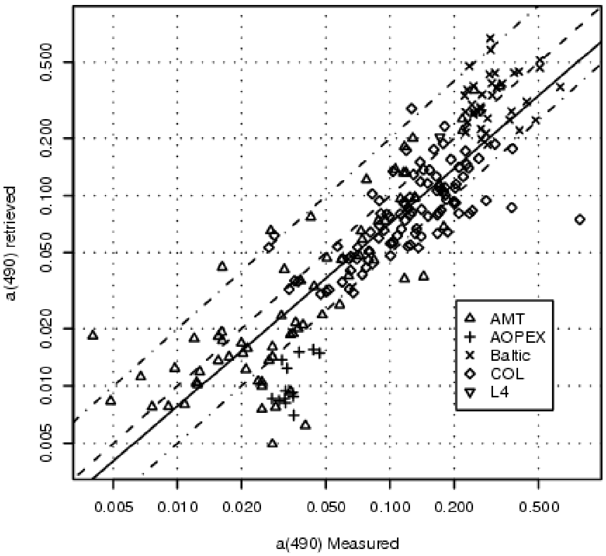


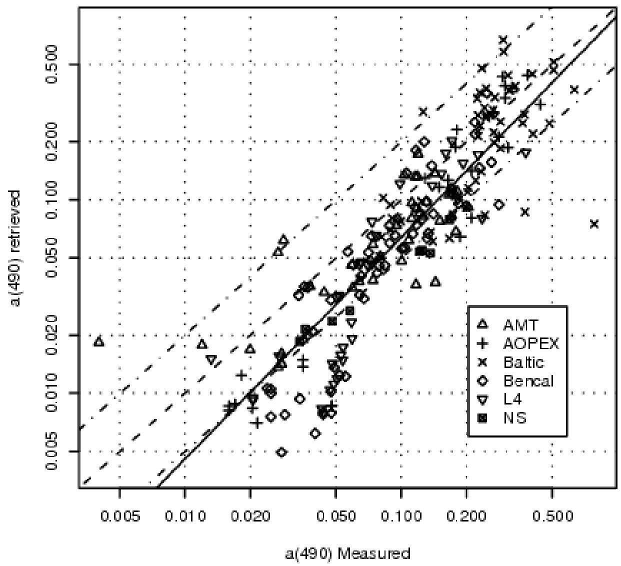
R2 .079, n- 79, p<.05

R Squared 0.7692536
RMS 0.01342134
BIAS 0.1925752

Figure 2a shows the relationship between b~(490) to b_b measured. 'b~(490)' is the ratio of back-scattering coefficient 'b_b', derived from concurrent measurements of 'b_b' by the VSF-3 (3 wavelength volume scattering function meter) to the scattering coefficient 'b' measured by the ac-9. This ratio (b~) is often taken as a constant (value 0.018 approximately) but this analysis shows that there is evidence that it is a declining function of 'b_b' over the range 0.02 to 5.0, though the regression analysis is not very significant.

Figure 2b shows 'b_b(490)' retrieved from the model regressed against 'b_b' calculated from 'b' measured by ac-9 multiplied by 'b~' estimated from the data shown in figure 2a. The results show significant fraction of variance explained (R^2 = 0.77) a small RMS error and a moderate bias.

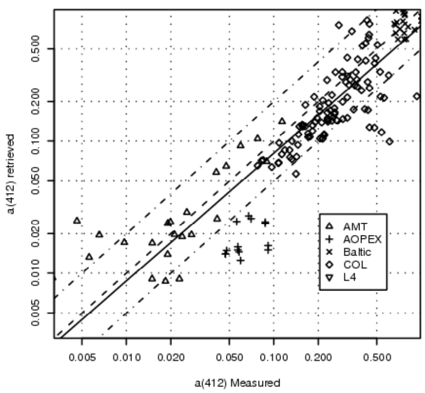


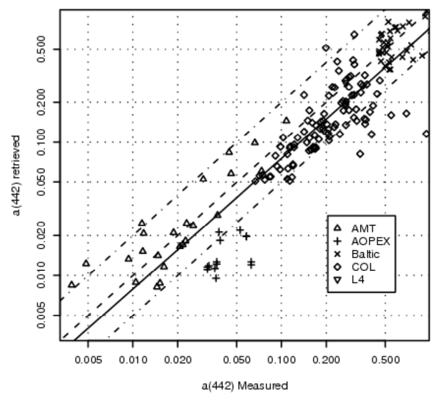


R Squared 0.7910032
RMS 0.075383
BIAS -0.1711549
a = 0.7421298 n = 1.013734
N-217

Before ac-9 reprocessing

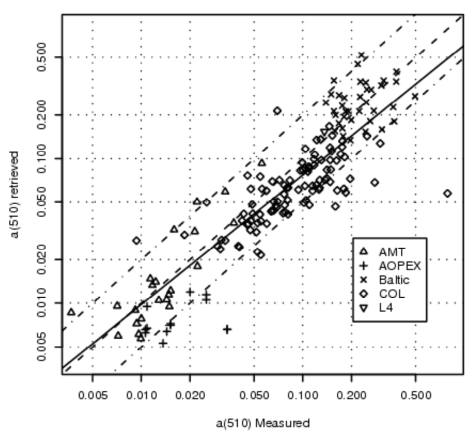
Figure 3a (the right hand panel) shows the regression of a(490) retrieved against a(490) measured by ac-9 before a new data correction (retro-calibration) scheme had been applied. Even with scruprulous calibration, before after and during research cruises, using cleanest sources of water, the ac-9 habitually gave anomalously high values of absorption at low values (cleanest water). It was an obvious conclusion the shape of ac-9 profiles deep in the water (40 m or more below the DCM) that water contanimatnts were affecting the measurements. A correction procedure was applied by computing the contribution from dissolved compounds and non-biogenic particles and the results used for comparison with model retreivals.
Figure 3b (left panel) shows a(490) retrieved regression against a(490) measured after correction by the methods desctibed above. The improvements in the fraction of variance explained, the RMS error and the bias are significant.

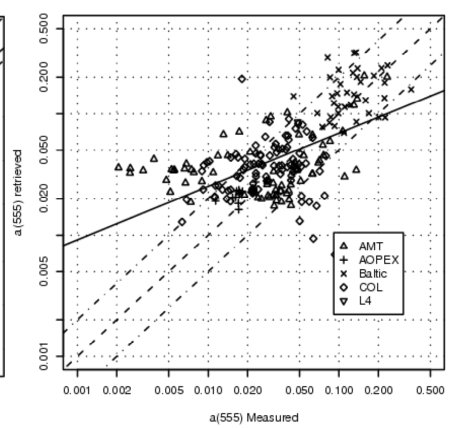




R Squared 0.7949715
RMS 0.2255985
BIAS -0.02469145
a = 0.7624567 n = 0.9737346
N - 169

R Squared 0.8303205
RMS 0.1350372
BIAS -0.1537992
a = 0.7395196 n = 0.9956861
N - 169

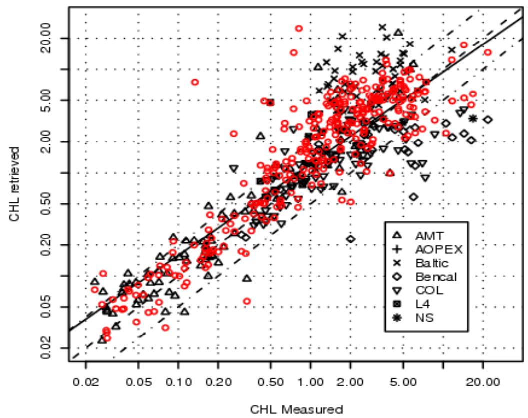




R Squared 0.7912151
RMS 0.06354974
BIAS -0.1144615
a = 0.724075 n = 0.9740136
N - 169

R Squared 0.3142476
RMS 0.04468868
BIAS 0.8411125
a = 0.1895955 n = 0.4386781
N - 217

Figure 4 shows the retrieved versus measured values of a(412), a(443), a(510) and a(555). The results are accepatable for all but a(555) though the range of values is lower in this case. The error is believed to arise from Raman scattering at 555nm that is not included in the model. Further developments are to include Raman scattering for wavelengths of 555 nm and longer and this we expect to achieve the desired modification.



IOP – Case I Chlorophyll
Coefficients
– Morel & Antoine 1993
R Squared 0.7333088
RMS 4.30339
BIAS 0.6966157
a = 1.222306 n = 0.8867378

OC4V4(red)
R Squared 0.7820314
RMS 58.90534
BIAS 1.616217
a = 1.470827 n = 0.9711914
N - 303

Figures 5. Shows the regressions of case 1 Chlorophyll retrieved from the model or by the NASA OC4V4 algorithm against Chlorophyll measured in situ in both case 1 and case 2 waters. Most notable is the result that RMS error is reduced for the IOP model by over an order of magnitude and the bias is halved.

CONCLUSIONS

The Moore et al bio-optical model has been tested extensively and has been shown to provide improved retrievals of Chlorophyll, diffuse attenuation coefficient and other biogeophysical optically active variables in marine waters, from bio-optical data (and potentially remotely sensed ocean color). These data could be used in heat budget models directly, or indirectly through parameterisations of kd(λ). Other developments not reported are the use of the model for the interpretation of phytoplankton functional types that can be used to validate complex ecosystem models using ocean color data; see references listed below.

TRANSITIONS

The modified version of the SeaDAS msl12 is being used by the CASIX project and the PML remote sensing group. http://www.npm.ac.uk/rsdas/

RELATED PROJECTS

NERC, CASIX some of the outputs of this project will be used to drive the remote sensing element of the CASIX project. http://www.pml.ac.uk/casix/

REFERENCES

Aiken et al in press. Validation of MERIS reflectance and chlorophyll during the BENCAL cruise, October 2002: preliminary validation of new demonstration products for phytoplankton types and photosynthetic parameters.

PUBLICATIONS See above.